NUMERIC MODELLING IN UDEC OF THE TINYAG MINE EXPLOITATION

MODELO NUMÉRICO DE EXPLOTACIÓN DE LA MINA TINYAG EN UDEC

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DCR Ingenieros Sociedad Limitada. (Geomecánica en Minería y Obras civiles). C/Altamira 124 urb. Camino Real. La Molina. Lima 12. Peru.

RESUMEN: El objetivo de este artículo es realizar un modelo numérico simplificado de las labores de explotación con minería subterránea (método de hundimiento por subniveles) de la mina Tinyag, para estimar el posible comportamiento del macizo rocoso afectado por las labores y, así, detectar posibles mecanismos de rotura (rotura circular, vuelco, etc.). El modelo también resulta interesante para identificar los mecanismos de hundimiento y subsidencia asociados. En definitiva, se pretende tener una visión aproximada de los riesgos geomecánicos existentes. Para llevar a cabo este modelo se ha utilizado el código UDEC, código numérico basado en el método de los elementos discretos.

PALABRAS CLAVE: modelo numérico, UDEC, hundimiento por subniveles, rotura, subsidencia.

ABSTRACT: The aim of this paper is to perform a simplified numeric model of the labours in the Tinyag underground mining exploitation (sublevel caving method), in order to estimate the possible behaviour of the rock mass affected by the labours, and to detect possible failure mechanisms (circular failure, toppling, etc.). The model is also interesting to identify the subsidence mechanisms associated. After all, it is expected to have an approximate vision of the existent geomechanical risks. We have performed this model using UDEC, a code based in the discreet elements method.

KEYWORDS: Numeric modelling, UDEC, sublevel caving, failure, subsidence

1. INTRODUCTION

The Tinyag mine is located at Iscaycruz (Figure 1) – Oyón province, Lima department, Peru - and belongs to the mining company Los Quenuales S.A.. The mine is 4700 m.a.s.l. in the Andes.

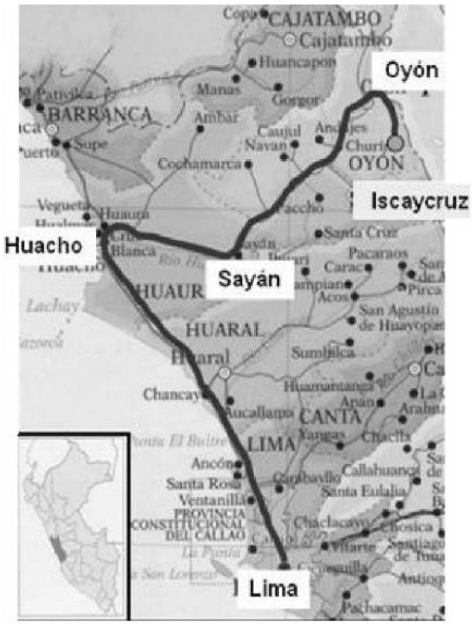

Figure 1. Situation map of the Tinyag deposit

The upper part of the deposit – till an elevation of 4544 m.a.s.l.– has been exploited by means of opencast mining (Figure 2). This exploitation has already been concluded because it had been reached the economic limit. Below that elevation, it is planned to continue the exploitation by means of underground mining, using the sublevel caving method, to be precise. This mining method has been proposed by Córdova et al. 2007 [1]. Their work is based on the studies of other authors (Kvapil [2]; Bull & Page, 2000 [3]; Laubscher, 1994 [4]; Rustan, 2000 [5]), on the design proposed by a consulting Chilean company (Krstulovic y Ovalle, 2004 [6]) and on the experience acquired in the design of the Rosaura mine (Córdova, 2004 [7]). Furthermore, we think that it can be proved that the sublevel caving method is a suitable exploitation method in this case, following the method suggested in Nicholas & Marek (1981) [8].

Figure 2. Photograph of the open pit exploitation

Tinyag is a semi-tabular deposit, oriented parallel to the stratification, 200 m long, and between 15 and 25 m thick. The ore is scattered in a skarn, forming sulphide massive bodies, mainly Zn. The average grade in Tinyag is 7.7 % Zn. In the hanging wall there are horizons of pyrite, oxides, silica, quartzite-marls and quartzite. In the footwall there are horizons of pyrite, shales and altered shales, dolomitic shales with sandstones, and sandstones with shales.

The aim of this work is to carry out a simplified numeric model of the labours in the Tinyag underground mining exploitation, in order to estimate the possible behaviour of the rock mass affected by the labours, and to detect possible failure mechanisms. It is foreseen that circular failure or toppling could be the most probable failure mechanisms. The model is also interesting to identify the subsidence mechanisms associated to the sublevel caving method. After all, it is expected to have an approximate vision of the geomechanical risks that we are going to face. We think that the numeric model will make an important contribution to achieve these goals.

We have used UDEC (Universal Distinct Element Code), developed by Itasca (2004) [9], to carry out this model. UDEC is a numeric code based in the discrete elements method. UDEC simulates the behaviour of discontinuous media subjected to loads. The discontinuous medium is represented by means of discrete blocks connections, which can behave as rigid or deformable blocks. Joints and discontinuities are considered as contour conditions between blocks. This allows great block displacements, including its separation and rotation. This is considered one of the main advantages of UDEC among other codes.

This code includes several behaviour models, which make easier the modelling of different materials and geological structures. UDEC is based in lagrangian calculations, very suitable for the simulation of great displacements and deformations in a medium formed by blocks. UDEC is especially suitable to detect physical instabilities in rock mechanics engineering problems, related with open pit or underground mining.

2. MODEL DEVELOPMENT AND RESULTS

The model was developed taking into account the geological sections and the geometry of the mine, provided by David Córdova, consultant of the exploitation. There have been also used the available consultancy reports to propose a simplified model (Figure 3).

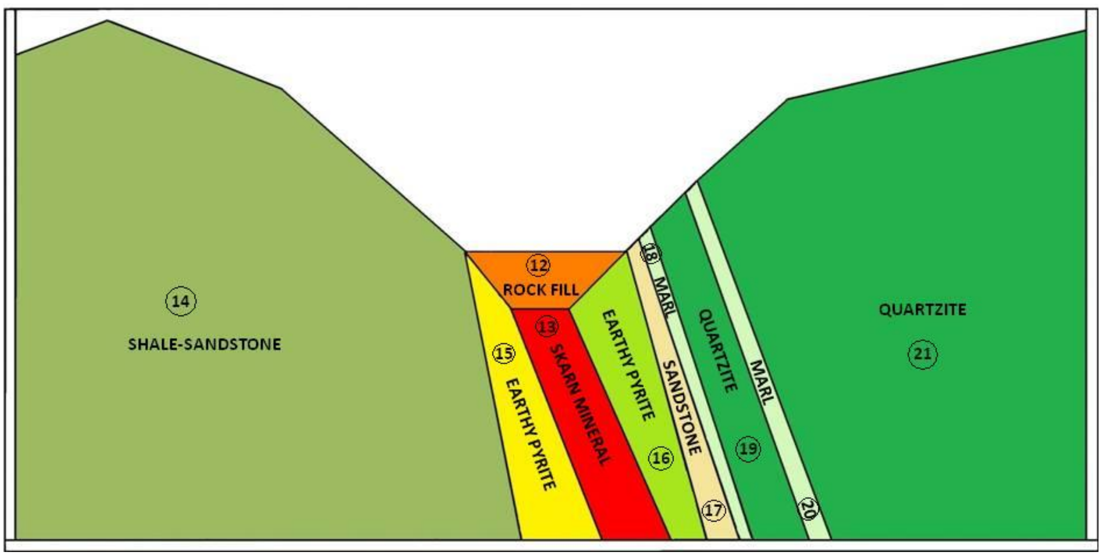

Figure 3. Simplified model of the geological cut of the Tinyag mine

Therefore, we distinguish 9 different rock masses, plus a rock fill added to the sill. Those materials have been numbered from 12 to 21, as follows:

12. Rock fill
13. Skarn mineral
14. Shale-sandstone
15. Earthy pyrite
16. Earthy pyrite
17. Sandstone
18. Marl
19. Quartzite
20. Marl
21. Quartzite

The skarn mineral, the earthy pyrite and the rock fill have been considered as discontinuous material. This material constitutes blocks according to three joint sets, which form angles of 0, 70 and 110 degrees to the horizontal. The rest of the layers have been modelled as a continuous deformable media.

Iscaycruz has a geomechanical database with the format recommended by the ISRM (Brown, 1981 [10]). This database is periodically updated. The geomechanical properties of the different rock masses (table 1) are referred to the strength and elastic parameters. These properties were estimated according to the Hoek & Brown's failure criterion (Hoek & Brown, 1980 [11]; Hoek & Brown, 1988 [12] and Hoek et al., 2002 [13]), with the help of Bieniawski's RMR (1989) [14], and also with the aid of the RocLab software (Rocscience, 2002 [15]).

Table 1. Geomechanical properties of the Tinyag rock mass

Lithology	Cohesion (KPa)	Friction angle	Deformation modulus (MPa)	Poisson ratio	Bulk Modulus (K) (MPa)	Shear Modulus (G) (MPa)
Pyrite	80	24°	285	0,3	238	110
Sandstone	120	28°	1500	0,28	1136	586
Marl	100	24°	620	0,28	470	242
Quartzite	180	31°	2500	0,25	1667	1000
Ore	130	31°	1010	0,28	765	395
Skarn	130	31°	1600	0,28	1212	625
Shale	140	29°	1800	0,26	1250	714
Rock drill	5	35°	80	0,35	89	30

The shear strength characteristics of the existent joints in the different rocks are controlled by the friction and cohesion parameters of the Mohr-Coulomb failure criterion (Mao-Hong Yu, 2002 [16]). The determination of these parameters was based on in-place characterization of JRC, JCS and basic friction angle. The results of these essays are presented in table 2.

Tabla 2. Properties of the discontinuities

Lithology	Cohesion (KPa)	Friction angle
Pyrite	-	-
Sandstone	53	30°
Marl	-	-
Quartzite	66	30°
Ore	63	32°
Skarn	74	30°
Shale	3	27°

On the other hand, we put forward the exploitation sequence pointed out in figure 4, where the ore is being extracted in 4 phases, following a numerical sequence from 1 to 4. This exploitation will produce a progressive subsidence and affections to the rock mass.

Thereby, the model would be the one shown in figure 5, where we can observe that phase 1 has already been exploited. As we can observe in figure 6, the collapse of the blocks takes place as the model is running. These blocks tend to fill the exploited area. The blue arrows represent the displacement vectors of the different blocks.

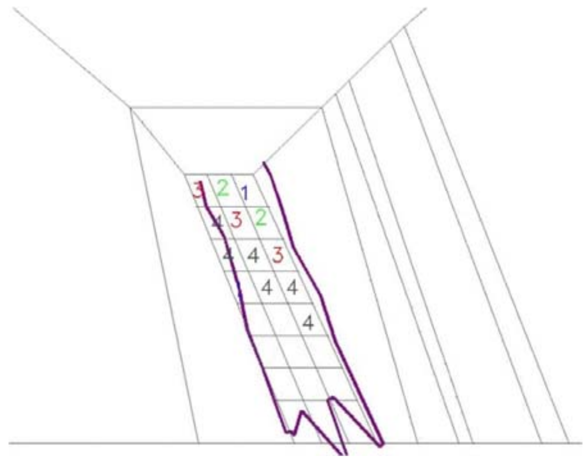

Figure 4. Exploitation sequence in the Tinyag mine

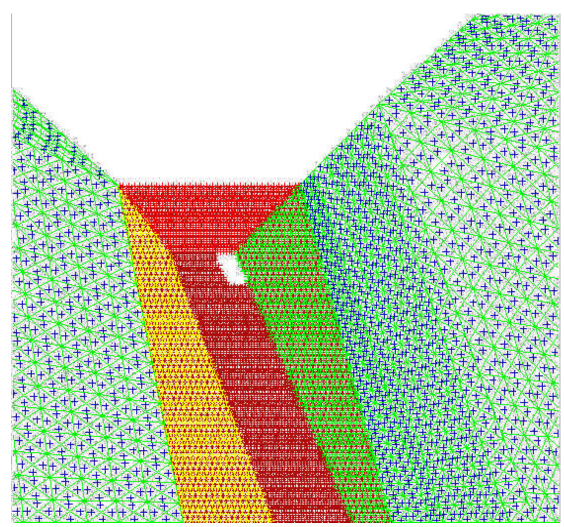

Figure 5. UDEC model of the Tinyag mine. Phase1

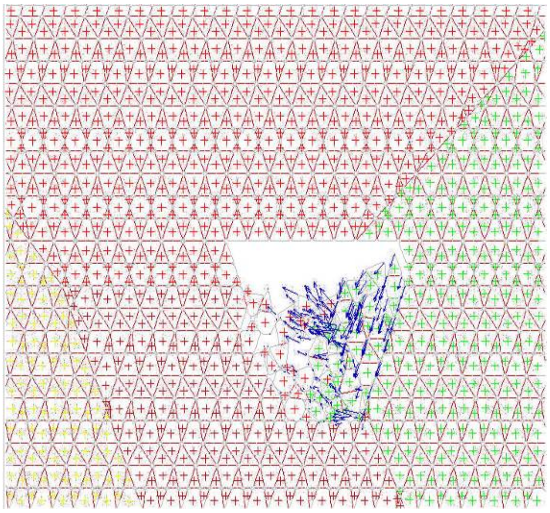

Figure 6. Collapse of the blocks after the mining of the ore in phase 1

In figures 7 and 8, we can observe the exploitation phase 2 in its beginning and in its ending. At the end of phase 2, we can observe that a certain subsidence has been produced in the surface. The subsidence phenomena should always be taken into account when the sublevel caving method is used. This phenomenon has being studied from the 70's (Hoek, 1974 [17]). We can estimate the area affected by subsidence by means of the fracture and drop angles (Cavieres and Díaz, 1993 [18]), but the aim of this paper is just the numerical modelling of the subsidence. The authors of this paper have already some experience in this subject (Alejano et al., 1999 [19]).

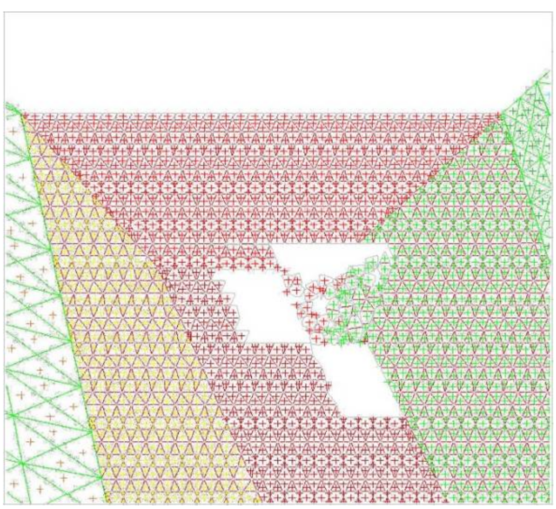

Figure 7. Phase 2 - Beginning

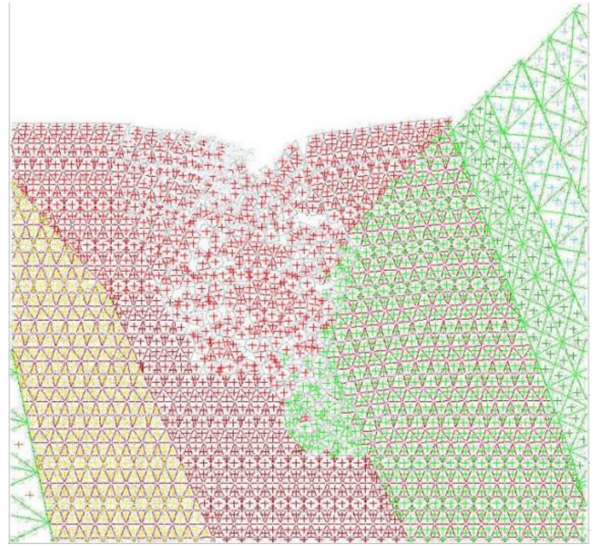

Figure 8. Phase 2 - Ending

In the exploitation phase 3 (figures 9 and 10), we can observe that, besides the subsidence, certain toppling begin to take place. We can identify this phenomenon through the cracks and steps produced in the surface.

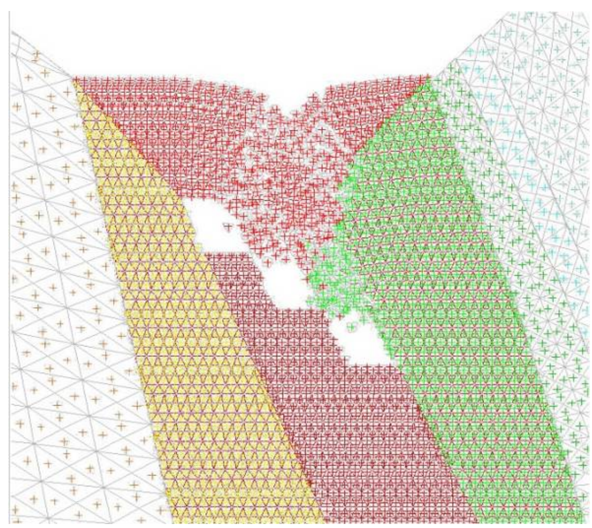

Figure 9. Phase 3 - Beginning

When the model reaches the phase 4 (figures 11, 12 and 13), large deformations and large shear stresses are produced. These stresses induce plastic deformations that could give rise to circular failure (red asterisks in figure 13).

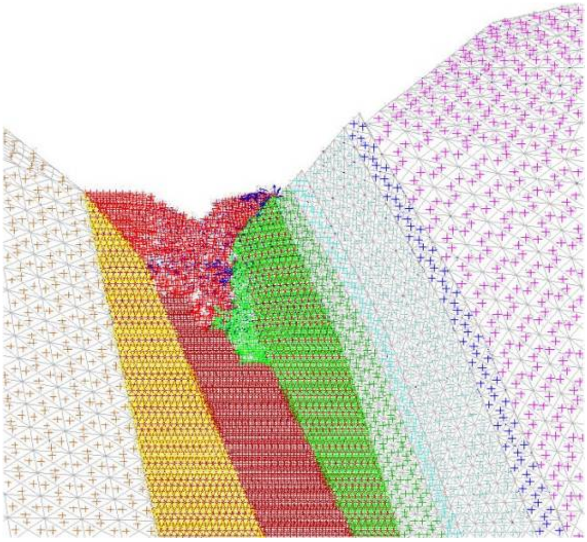

Figure 10. Phase 3 - Ending

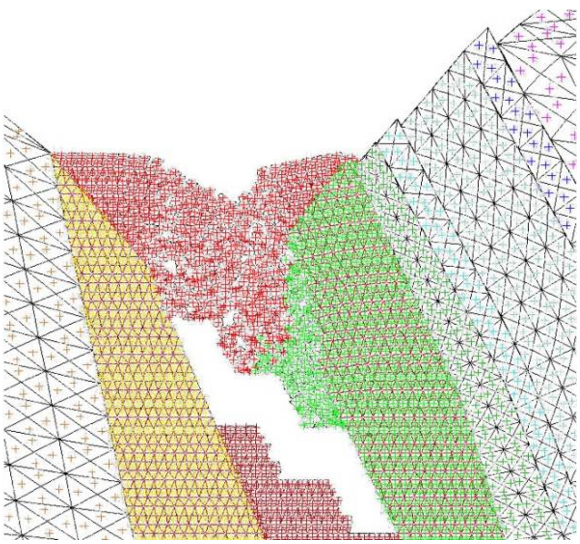

Figure 11. Phase 4 - Beginning

3. CONCLUSIONS

A numeric model of the Tinyag mine exploitation, in Peru, has been built with the aid of the UDEC code. The underground mining method selected is the sublevel caving method. The aim of this work is to assess the behaviour of the rock mass affected by the exploitation and to identify the possible failure and subsidence mechanisms that could take place.

In the numeric model, the exploitation has been carried out in 4 phases, and we have been able to observe how the collapse of the rock mass takes place, as described by other authors like Kvapil (1992) [2]. We have observed also that a subsidence occurs in the surface, as it is usual in sublevel caving and as it actually happened in the Tinyag mine, as we can see in figure 14.

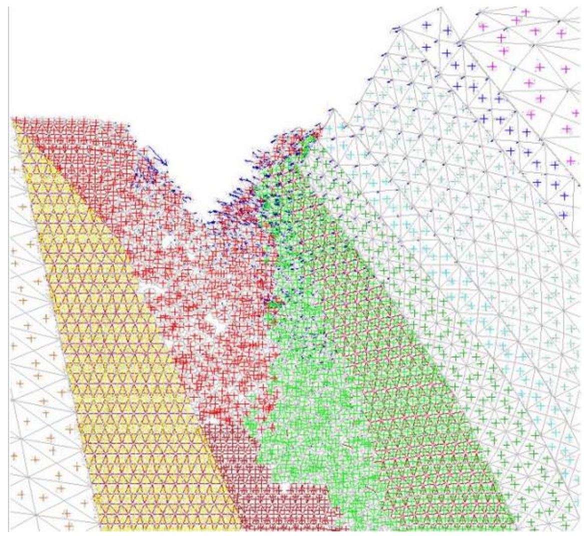

Figure 12. Phase 4 - Ending

Finally, we have observed that toppling of the blocks in the hanging wall could take place and, as a matter of fact, tensile cracks have arisen in the mine wall, as we can see in figure 15. Moreover, we have observed that large shear stresses and large plastic deformations can show up. And we think that these stresses could give rise to a circular-type failure in the back wall (figure 13).

Therefore, we believe that the appropriate studies and the adequate actions should be taken to avoid these studied phenomena to take place or, at least, to avoid any human or equipment loss.

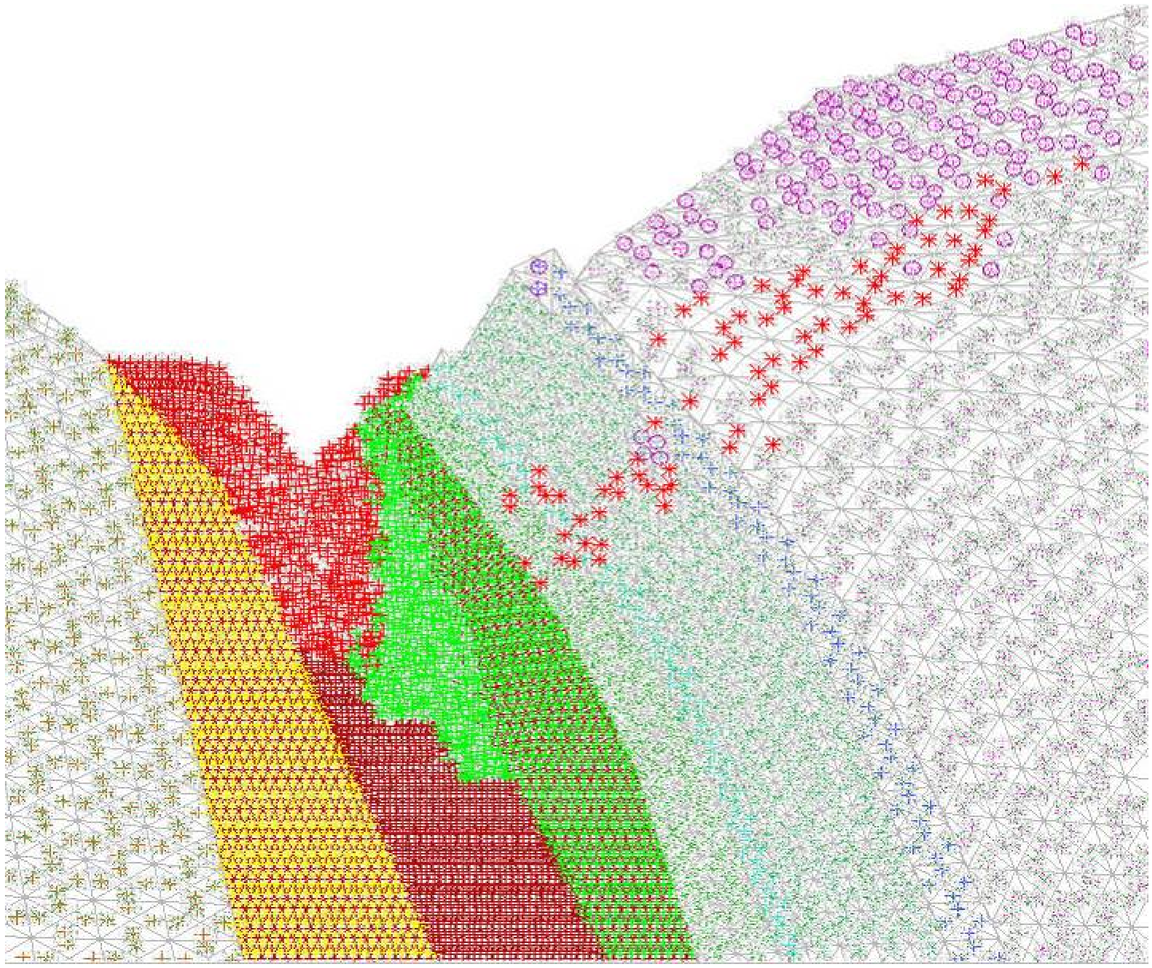

Figure 13. Phase 4 – Plastic deformations (red asterisks) produced by shear stresses

Figure 14. Subsidence in the bottom of Tinyag mine.

Figura 15. Tensile crack in a slope of the Tinyag mine.

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